

The Effect of a Magnetic Field Upon the Absorption Spectra of Cer- tain Rare Earths

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THE EFFECT OF A MAGNETIC FIELD UPON THE ABSORPTION SPECTRA OF CERTAIN RARE EARTHS

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INTRODUCTION

Although the great majority of solid substances when heated to incandescence give a continuous emission spectrum, it was discovered by Bunsen¹ in 1864 that didymium emits a bright band spectrum under these conditions. The same phenomenon was observed with erbium by Bahr² in the following year, and since then a few more of the rare earths have been shown to possess the same peculiarity. The absorption spectra of these rare earths are of special interest, it being by means of these spectra that some of them were discovered. So far neodymium, praseodymium, samarium, erbium, holmium, dysprosium, thulium, and europium are the only ones found to give a line absorption spectrum. Because of their interest and peculiarities, the comparatively great number of bands, and the relatively small width of some of the latter, these substances have been the subject of spectroscopic investigation by a large number of observers.

One of the methods extensively used is to form the absorption spectrum by means of a beam of intense light after reflection from one of the salts of the element to be studied. This method was first used by Haidinger³ in 1852.

As some of the results of these experiments have a direct bearing on the subject of this research they will be briefly reviewed here.

It was noted as early as 1831 by Brewster that the transparency and color of certain solids were altered when they were heated, but Conway in 1891 was the first to make spectroscopic measurements of this change and showed that the bands of cobalt glass were shifted toward the red end of the spectrum as the temperature increased.

Recently J. A. Anderson⁴ investigated the effect of increase of temperature upon the absorption bands of erbium and neodymium

¹ *Liebig's Annalen*, **131**, 255, 1864.

³ *Wien. Ber.*, **8**, 97, 1852.

² *Ibid.*, **135**, 376, 1865.

⁴ *Astrophysical Journal*, **26**, 73, 1907.

compounds, and J. Becquerel,¹ using liquid air as a cooling medium, experimented with crystals containing these and other rare earths, and also with solutions of their salts in various alcohols, the solutions of course being solid at the temperature used.

The effect upon the absorption bands was threefold: As the temperature was lowered, they were shifted from their original positions; they became narrower and sharper, and at the same time more intense. Some of the bands were shifted toward the red end of the spectrum, while others moved in the opposite direction.

J. Becquerel and J. K. Onnes² later repeated the experiments, using liquid hydrogen for the cooling bath. It was found that at this lower temperature some of the lines again became broader, some of them actually disappearing, whereas new ones appeared which were not observed at ordinary temperatures.

Becquerel³ also studied the effect of a magnetic field upon the absorption bands of the transmission spectrum of these crystals, both at ordinary and at very low temperatures. It was found that some of the bands were not at all affected, others simply becoming broader and changing in intensity in the magnetic field, whereas in yet others the effect was similar to the Zeeman effect in vapors. The magnitude of these effects was found to be proportional to the strength of the field and independent of the temperature. Uniaxial and biaxial crystals were used and naturally the effect depended upon the relative positions of the crystal with respect to the beam of light and the direction of the magnetic field. The result of this investigation may be briefly described as follows:

Case I.—The beam of light perpendicular to the direction of the magnetic field.

The spectrum corresponding to rays polarized perpendicular to the field differed from that corresponding to rays polarized parallel to the field. Certain rays were split up into triplets, the outer components of these triplets, for some bands, being found in one of the above spectra, for other bands in the other spectrum.

As the optical axis of the crystal was rotated in a plane parallel to the beam of light and to the direction of the lines of force, it was

¹ *Comptes Rendus*, **144**, 420, 682, 1032, 1336, 1907.

² *Ibid.*, **146**, 625, 1908.

³ *Ibid.*, **142**, 775, 874; **143**, 890, 962, 1906; **144**, 132, 1907.

found that some of these components in the ordinary spectrum themselves split up into a doublet, some of the new components increasing in intensity as the rotation proceeds, others becoming feebler and finally disappearing. The displacement of some of the bands is greater than would be expected from a knowledge of the Zeeman effect. At ordinary temperatures the field-strength used was in the neighborhood of 30,000 Gauss, but at the lower temperatures the separation could be noted with field-strengths of about half this amount.

Case II.—The beam of light parallel to the field of force.

If we were observing the Zeeman effect upon the emission lines of a vapor under this condition, and passed the light through a quarter-wave plate and a rhomb of spar properly oriented, we would see in the spectrograph two contiguous spectra, plane polarized at right angles to each other. These two spectra correspond to light circularly polarized in opposite directions. The circularly polarized components of each doublet produced by the magnetic field are equally displaced from the position of the original line, but in opposite directions.

For this arrangement of the apparatus Becquerel obtained components of his bands which were shifted in opposite directions in the two spectra. We may think of these components as corresponding to circular vibrations in opposite directions, the direction of vibration being in each case opposite to that of the light which actually gets through the apparatus when the plate and prism are not inserted, and Becquerel so speaks of them.

He found also that in the same spectrum the components of different bands were shifted in opposite directions.

Since in the Zeeman effect the rays corresponding to negative electrons with paths in the same sense as that of the magnetizing current are always shifted toward the shorter wave-lengths, the above fact would indicate that there are positive electrons present in the crystals, or else that there is a change of direction of magnetic field within certain atoms. Becquerel accepts the first of these hypotheses.

He calculated the value of e/m for these positive electrons from the separation of the components of different bands and found it to be from three to nine times the value of this ratio for cathode particles.

Rotary magnetic polarization was observed¹ by passing a beam of plane-polarized white light through a plate of crystal cut normal to the axis, and then through a rhomb of spar placed in front of the slit of the spectrograph and so oriented that two contiguous strips, polarized in different planes but having the same intensity, could be seen at the same time. When a magnetic field was set up parallel to the incident beam the bands of the ordinary absorption spectrum were found to change in intensity. The bands corresponding to negative electrons, in one of the strips, became more intense and narrow, whereas those corresponding to positive electrons became less intense and broader. In the other strip the effect was just reversed, and the whole effect was reversed when the direction of the field was changed by reversing the magnetizing current. Becquerel states that "on each side of the absorption bands which form a doublet, the rotatory power is positive (in the sense of the magnetizing current) if the band corresponds to negative electrons, and negative if the band corresponds to positive electrons. Within each band or between the components of certain of them, the sense of the rotation is opposite to that outside of the band."

Becquerel mentions² that these crystals contain paramagnetic substances (erbium, didymium, etc.). Now according to Curie's law paramagnetic susceptibility is proportional to the absolute temperature, whereas diamagnetism is independent of the temperature. Having found that the change of period of vibration of electrons in these crystals is independent of the temperature, he seeks for a connection between these changes and diamagnetism.

From his theoretical investigation Becquerel concludes, that the period of the motion proper to the electrons is not influenced by the temperature in the solid body, but that the resistance experienced by the electrons in vibration increases and diminishes with the temperature. An analytical investigation of these effects led W. M. Page³ to the following conclusions:

1. If the electron is easily displaced from its equilibrium position, a large separation of the components of the doublet will result from the action of a magnetic field.

¹ *Comptes Rendus*, **142**, 1144, 1906; **144**, 682, 1907.

² *Le Radium*, **5**, 5, 1908.

³ *Cambridge Phil. Soc. Trans.*, **20**, No. 13, 291, 1907.

2. If the friction is small the bands will be very dark and narrow, while if the friction is large, the bands will be wide and will shade off very gradually from the point of maximum intensity. Thus when the crystal is acted on by a magnetic field, the components of the resulting doublet will run into one another and the separation will not be observed, though the bands on the whole will increase in breadth.

3. The fact that some of the bands observed broaden for some directions of the vibrations and separate for others, is held to indicate that the friction is different in different directions.

4. The vibrations are preferably ascribed to negative electrons in all cases, it being held that in the neighborhood of systems that give "inverse" displacements, the magnetic field changes sign, i. e., that these inverse effects are diamagnetic in character.

OBJECT OF THIS INVESTIGATION

The fact was brought out by Anderson that when an absorption spectrum was obtained by reflection from the fused surface of the oxide of erbium or of neodymium, the spectrum was identical with that obtained from the unfused oxide except that the absorption bands were very much more intense in the former. This indicated that the absorption bands are really due to the fact that the light is transmitted through a thin layer of the substance, the increased intensity being due to the longer path through the more transparent fused oxide.

It was therefore determined to investigate whether the absorption bands obtained in this manner are affected by a magnetic field in the same way as those obtained by transmission through crystals.

PREPARATION OF MATERIALS

The salts of erbium and of neodymium are known to show a large number of absorption bands which are comparatively narrow and sharp. It was therefore determined to use the oxides of these elements as the reflecting surfaces.

The chlorides of these elements¹ were first precipitated by the addition of a concentrated solution of oxalic acid. After being washed with hot water to remove any remaining oxalic acid, the precipitates were dried and then heated in porcelain vessels to a red heat, being

¹ The chlorides used were some of those prepared by Dr. Anderson during his investigation of these elements.

thus converted into oxides. The erbium salts were found to be free from neodymium, praseodymium, and holmium.

To use these oxides as reflecting surfaces they were formed into small plates about $\frac{1}{2} \times 2 \times 3$ mm in dimension. The powdered oxide was moistened with chloride solution and then packed into a small glass mold, a fine platinum wire being forced into the mixture before it hardened. By means of this wire the plates were readily handled after they were dried. The plates were toughened by alternately dipping them into the chloride solution and gradually heating them to redness.

As was shown by Anderson the absorption bands obtained from these oxides are much darker and more distinct if the reflecting surfaces are fused. The plates of erbium were therefore heated for several hours in the oxyhydrogen flame after they had been toughened. It was found that the neodymium oxide when treated in this manner became so dark that it was rendered unfit for use. It was therefore heated for several hours in the Bunsen flame and then for only a short time in the oxyhydrogen flame.

ARRANGEMENT OF APPARATUS

The spectrum was observed by means of a fixed-arm spectrograph having an objective with a focal length of 160 cm. A plane Rowland grating on speculum metal having a space of $3\frac{3}{8}$ inches ruled with 20,000 lines to the inch was used.

The reflecting plate was placed between the poles of a large Ruhmkorff electromagnet,¹ and was strongly illuminated by focusing the light from the positive pole of a carbon arc lamp upon it, the reflected beam being focused upon the slit of the spectrograph.

In order to observe side by side the spectra polarized in planes perpendicular to each other, the beam of light was passed through a properly oriented double-image prism before falling on the slit of the spectrograph.

METHOD OF OBSERVATION

The reflected beam of light was rather faint, and it was found advantageous to focus the light upon the slit by means of a cylindrical lens. The effect of the magnetic field upon the absorption bands

¹ For some of the observations, use was made of a small du Bois magnet belonging to the U. S. Bureau of Standards.

could, however, be plainly seen with the naked eye except in the region of short wave-lengths.

In order to measure the effects more accurately and to compare the spectra obtained with and without the magnetic field, they were photographed.

The two spectra were observed side by side by alternately masking the two halves of the slit. But the camera was so arranged that when this was not possible, a freely moving screen could be moved up and down in front of the plate, this screen having a slit large enough to permit the full spectrum (obtainable with this apparatus) to be photographed.

This spectrum covered a range of 500 Ångström units, and it was proposed to study in particular three groups of bands of erbium oxide, which were more intense than the others, and which were found in the regions between λ 4450 and λ 4760, λ 5150 and λ 5650, λ 6300 and λ 6800, respectively. (See Figs. 1 and 2.)

In the case of neodymium oxide the band at λ 4375.2 and those lying between λ 5300 and λ 5500, and between λ 5800 and λ 6200 were observed.

The time of exposure was limited because of the heating of the electromagnet, owing to the heavy currents which were required to produce the strong fields that were used. It was therefore necessary to use the quickest photographic plate that was sensitive in the particular region to be investigated. A large number of plates of various kinds were experimented with, and finally the following were chosen as giving the best results in the limited time at our disposal: for the blue region of the spectrum, Seed's Gilt Edge No. 27; for the green region, Cramer's Isochromatic; and for the red region, the Wratten & Wainwright Panchromatic plates.

In order to gain the advantage of narrow and intense bands at low temperatures, an attempt was made to cool the reflecting plate by directing a fine stream of ethyl chloride upon its surface. The effect produced was hardly noticeable and this method was abandoned. The air gap between the poles of the electromagnet was generally less than one millimeter in order to obtain the strongest possible field, so that it was impracticable to immerse the plate in liquid air within this gap.

A water-screen was for a time placed in the path of the incident beam to prevent heating of the reflecting plate, but this was found to be unnecessary, the heating effect being negligible in comparison with the magnetic effect.

Several photographs were taken of the second-order spectrum but nothing new was brought out by these, and as the time of exposure was limited, the majority of the photographs were taken of the first-order spectrum.

The effect of the magnetic field was observed: (1) when set up perpendicular to the beam of reflected light, and (2) when set up parallel to this beam. In the latter case a quarter-wave plate and double-image prism were arranged in the manner already described, which would in the case of the ordinary Zeeman effect give two spectra corresponding to circularly polarized components of opposite sense. We will speak of the two spectra obtained in the case of absorption bands, as corresponding to opposite circular vibrations, using this phrase in the same sense that Becquerel used it.

The core of the magnet was bored with a $\frac{3}{4}$ -inch hole, the pole piece with a $\frac{3}{8}$ -inch hole. The axis of this opening was in line with the middle of the slit and with the center of the grating. In the first experiments a small right-angled prism was placed in front of this opening and an arc lamp to one side of the magnet, so that the beam of light reflected into the opening by the prism and falling upon the erbium or neodymium oxide plate retraced its path parallel to the lines of force.

The reflected beam was rather feeble and required so long a time for exposures that a strong field could not be used. The prism was therefore discarded and the following arrangement was substituted.

The reflecting plate was placed between the pole-pieces at an angle of about forty-five degrees with the direction of the field. The source of light was placed to one side of the magnet so that the light falling upon this inclined plate was reflected through the opening parallel to the lines of force.

There was no noticeable difference between the photographs obtained with these two arrangements.

RESULTS OF OBSERVATIONS

The field strength was varied from 18,000 to about 27,000 Gauss and the magnetic effect was found to be proportional to the strength of the field.

Erbium oxide. Case I.—The direction of the magnetic field perpendicular to the beam of light.

Under these conditions it was found that some of the bands were not appreciably affected. Others were considerably broadened both in the ordinary and in the extraordinary spectrum. It was observed, however, that the broadening was greater in one case than in the other, and upon examination with a Nicol prism, the broader of the two was found to be due to vibrations perpendicular to the lines of force of the field, the other being due to vibrations parallel to the field. Reversing the magnetic field did not alter the appearance of these bands. The narrower band evidently corresponds to the middle component of the ordinary Zeeman triplet, the broader band to the outer components. It was noticed, however, that in all the photographs the spectrum due to vibrations parallel to the field was considerably denser than the other, probably owing to the polarization introduced by the grating. The difference in width may therefore have been in part due to this different density.

Not even with the strongest field used could a positive separation of the two outer components be detected, although in some cases the width of the bands is increased in the magnetic field about one and a half times.

Still other bands were found to be shifted from their original positions when the magnetic field was set up. Some of these were moved toward the red end of the spectrum; others toward the violet end.

In other cases the bands were unsymmetrically broadened, the broadening being in opposite directions for different bands.

There is also a marked change in the intensity of the bands when in a magnetic field. As they become broader they decrease in intensity, some of them actually disappearing.

The difference in breadth of the bands in the spectra polarized at right angles to each other is clearly seen in the isolated band at λ 5197.0. This is shown in Fig. 3, which is the group marked "B"

in Fig. 1, but on a larger scale. Taking the average width of this band from three different plates it was found to be about 3.7 Å. U. when the field was not excited. In the magnetic field, the width changed to about 4.7 Å. U. and 5.1 Å. U. respectively for the two spectra, with a field strength of approximately 25,000 units.

In the same group the band at λ 5250.0 does not seem to be affected by the field.

The band at λ 5242.2 is much broadened, the width in the magnetic field being about one and a half times as great.

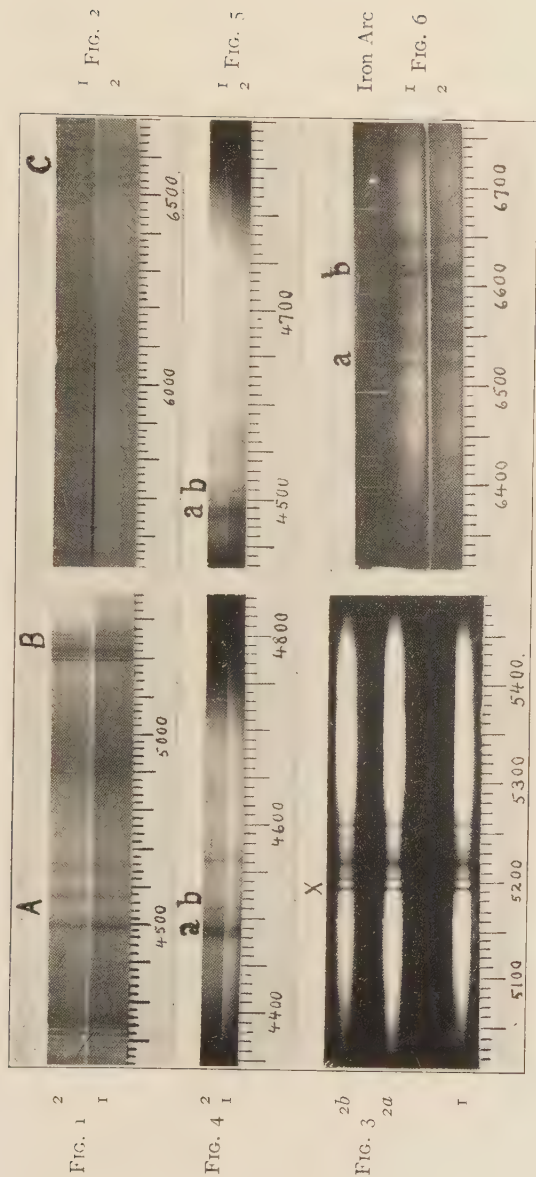
The bands at λ 5212, λ 5232, and λ 5268.8 in this group show marked decrease in intensity. The one at λ 5232 is no longer visible in the magnetic field. The one at λ 5212 may still be seen in the spectrum polarized parallel to the field but not in the other. The band at λ 5268.8 can be seen in the spectrum polarized perpendicular to the field, but not in the one parallel to the field.

The other bands in this group seem to increase in width in the manner first described.

Fig. 6 shows on a larger scale the group of bands marked "C" in Fig. 2. In this group the band at λ 6630 shows no appreciable change in the magnetic field. The one at λ 6617 is much broadened, the broadening being unsymmetrical and toward the red end of the spectrum. On the other hand, the band at λ 6524 also broadens unsymmetrically but toward the violet end of the spectrum. The other bands of this region are all more or less broadened.

In Figs. 4 and 5 the group marked "A" in Fig. 1 is shown on a larger scale. The band at λ 4499 shows no change in the magnetic field. The band at λ 4510.5 changes very little in breadth but is shifted toward the violet end of the spectrum by approximately 0.6 Å. U. for a field strength of 25,000 units. The broad band at about λ 4486 appeared to become narrower and more intense in the magnetic field. The narrowing seemed to be all on one side, but it was thought probable that the band was shifted, the shift of one edge being hidden by an emission band from the source of light at this point. This is shown in Fig. 4. To avoid this band, the spectrum was photographed by means of a Nernst lamp. The time of exposure was, however, so much increased that a strong field could not be used. A satisfactory photograph free from emission lines was finally obtained by making

PLATE XII



ERBIUM OXIDE

Spectra marked 1 were photographed without the magnetic field.
Spectra marked 2 were photographed with the field.

- Group A. Bands examined, between $\lambda 4450$ and $\lambda 4700$.
- Group B. Bands examined, between $\lambda 5150$ and $\lambda 5650$.
- Group C. Bands examined, between $\lambda 6300$ and $\lambda 6800$.

FIG. 4.—Group A of Fig. 1
Photograph with Carbon Arc.

- a. Band at $\lambda 4482.2$ shifted toward red.
- b. Band at $\lambda 4510.5$ shifted toward violet.

FIG. 3.—Group B of Fig. 1

- 2a. Vibrations parallel to field.
- 2b. Vibrations perpendicular to field.
- x. Band at $\lambda 5197$.

FIG. 5.—Group A of Fig. 1
Photograph with Acetylene Flame.

- a. Band at $\lambda 6524$ broadens unsymmetrically to violet.
- b. Band at $\lambda 6617$ broadens unsymmetrically to red.

use of the scheme devised by C. F. Lorenz,¹ the intensity of an acetylene flame being increased by passing an electric discharge through it. This photograph is shown in Fig. 5. It now appeared as though there was an unsymmetrical shift of the band, but upon close examination the band proved to have two distinct maxima. Under the influence of the magnetic field, the one at $\lambda 4482.2$ became broader and was shifted toward the red end of the spectrum by approximately $0.8 \text{ \AA. U.}$ for a field-strength of about 25,000 units. The other component of this band became broader in the magnetic field but retained its position.

The band at $\lambda 4562.6$ becomes somewhat broader and shifts slightly toward the violet side. The remaining bands of this group are all more or less broadened in the magnetic field.

Erbium oxide. Case II.—The lines of force of the magnetic field parallel to the beam of light.

The spectra produced under these conditions showed the same changes as those obtained when the field was perpendicular to the beam of light. The same bands as before became broader and the same bands were shifted from their original position.

No positive evidence of displacements in opposite directions of the two components of a band corresponding to opposite circular vibrations could be detected. To test the bands for circular polarization, the quarter-wave plate and a Nicol prism were placed before the slit and so oriented that if the edges of the band were circularly polarized one of them would be cut off. If, now, the direction of the field were reversed, the direction of polarization should change also, and the other edge of the band should appear, the first one being now cut off. No change of position of the bands resulted in this experiment.

It was thought that if plane-polarized light were used in the incident beam, there might still be some trace of polarization left in the diffusely reflected light, so that it might be possible to observe the effect noticed by Becquerel and ascribed to magnetic rotatory polarization, that is, the broadening of the bands due to negative electrons and the corresponding narrowing of the bands due to positive electrons, in the same spectrum. This was accordingly tried, but the photographs showed the same effect in all cases as when ordinary light was used.

¹ *Physikalische Zeitschrift*, **8**, 20, 1907.

Neodymium oxide.—The bands for this substance were in general broader and not so sharply defined as in the case of erbium oxide.

ERBIUM OXIDE

λ	Nature of Band	Effect
4482.2	Wide and intense	Broadens and shifts to red
4491.3	Wide and intense	Broadens
4510.5	Wide and intense	Broadens slightly; shifts to violet
4541.9	Narrow and intense	Broadens
4554.1	Narrow and faint	Broadens
4562.6	Broad and intense	Broadens and shifts to violet
4571.8	Broad; hazy	Broadens
4579.1	Broad; hazy	Broadens
4606.5	Narrow and faint	Broadens
4625.9	Broad and faint	Broadens
5197.0	Broad; sharp	Broadens
5205.5	Broad; sharp	Broadens
5212	Narrow; faint	Becomes very faint or disappears
5216.5	Narrow; faint	Becomes very faint or disappears
5232	Narrow; faint	Becomes very faint or disappears
5242.2	Narrow and intense	Broadens very much
5250.0	Broad and faint	Not affected
5261.0	Broad and faint	Broadened
5268.8	Broad and faint	Becomes very faint and disappears
5387.7	Broad and faint	Broadens
6430.0	Broad and faint	Broadens
6476	Broad and faint	Broadens
6496	Broad and very hazy	Broadens
6524	Broad and very hazy	Broadens unsymmetrically to violet
6538	Broad and very hazy	Broadens
6546	Broad and distinct	Broadens
6562	Broad and distinct	Broadens
6581	Broad and hazy	Broadens
6598	Broad and hazy	Broadens
6617	Broad and distinct	Broadens unsymmetrically to red
6630	Broad and hazy	Not affected
6652	Broad and hazy	Broadens

NEODYMIUM OXIDE

λ	Nature of Band	Effect
4375.2	Narrow; faint	Broadens
5355	Broad; dark	Broadens
5379	Broad; dark	Broadens
5403	Narrow; dark	Broadens
5853	Broad; edges hazy	Broadens
5902	Very broad; edges hazy	Broadens
6103	Very broad; edges hazy	Broadens
6148	Very broad; edges hazy	Broadens
6197	Broad; edges hazy	Broadens

The same experiments were carried out, but no new effects were observed. The general result of placing the substance in the magnetic field was to broaden the bands. None of these was observed to shift. It was noticed in the course of the investigation that the oxides of erbium and of neodymium are quite strongly magnetic. If not securely fastened, the reflecting plates were drawn into the strongest parts of the field, thus shifting the light from the slit or getting out of focus. A rod of the oxide, when suspended in the field so that it could rotate, placed itself parallel to the lines of force.

A table of the bands observed, their wave-lengths and appearance, and the effect of the magnetic field upon them is appended.

DISCUSSION OF RESULTS

It is known that the position of the absorption bands of an element is different for different compounds of the same element, and that it changes with temperature, concentration of solution, etc. The bands found for the erbium and neodymium oxides were quite different from those studied in crystals by Becquerel, and it was difficult to compare effects in the two cases. Becquerel gives the position of bands which gave him a large value of e/m for positive electrons as λ 5206.5, λ 5211.3, λ 5236.6, λ 5245.8, λ 6474.0, λ 6505.6, and λ 6542.5 for the erbium compounds. The bands obtained with the oxides in these neighborhoods were carefully examined, but no difference could be found between these and the others. He gives the band at λ 6571.6 as displaced toward the red end of the spectrum. In this neighborhood the band at λ 6617 for the oxide was also displaced toward the red.

As was pointed out by Page (*loc. cit.*) when the resistance to vibrations of electrons is great, the bands will be comparatively wide and the effect of the magnetic field will be to broaden them, the components overlapping each other. But even the narrow bands showed no complete separation of their components in this investigation.

The fact that no positive evidence of circular polarization could be detected may be explained by the fact that the light in order to show absorption bands must penetrate a thin layer of the reflecting substance. In its passage through this layer the light will change its direction from particle to particle, being at times more or less paral-

lel to the direction of the negative field, at times perpendicular to this field. Apparently the broadening of the bands due to the absorbing electrons when the path is perpendicular to the lines of force is sufficiently great to mask the effect when the light is parallel to the field, so that we see the broadening of the bands in all cases.

The unsymmetrical broadening of some of the bands in opposite directions may be really due to the fact that certain bands are much more affected by the magnetic field than others. If, for instance, a band is really double, the components lying so close together that they cannot be seen separately, and if one of these is much more affected than the other in a magnetic field, the broadening of this component will make the band as a whole appear to be broader and shifted in the direction of this component. The direction in which this apparent shift takes place will then depend upon which of the two component bands is the more broadened by the magnetic field.

SUMMARY

As a result of this investigation upon erbium and neodymium oxide, it may be stated that the absorption spectra obtained by reflection from these substances show the following effects in the magnetic field, for the temperature and field-strengths used:

1. Practically no difference was observed between the two spectra obtained, first with the light parallel to the field and secondly with the light and field perpendicular to each other.
2. Certain bands are not affected by the magnetic field.
3. Other bands appear to be shifted from their original positions, some toward the red, others toward the violet end of the spectrum.
4. Certain bands become broader in the magnetic field, the increased width appearing to be greater in the case of vibrations perpendicular to the field than for vibrations parallel to the field. This difference in width may be partly accounted for by the fact that one spectrum is denser than the other, which is probably due to polarization by the grating.
5. A number of bands were found to be unsymmetrically broadened, the broadening being in some cases greatest toward the red end of the spectrum, in other cases toward the violet end.

6. The intensity of the bands is altered in the magnetic field; some of them actually disappearing.

7. The oxides of both erbium and neodymium are paramagnetic.

In conclusion, I wish to thank Professor J. S. Ames, under whom this work was carried out, for his unfailing interest and advice during its progress. My thanks are also due to Dr. S. W. Stratton for the loan of the du Bois magnet.

BIOGRAPHICAL NOTE

William Frederick Schulz was born on January 11, 1872, in Baltimore, Md. His early education was received in the public and private schools of this city. In 1893 he successfully completed a special course in electrical engineering at the Johns Hopkins University.

During the years 1894-1899 he practiced electrical engineering in Baltimore and Pittsburgh. In 1899 he entered the graduate school of the University of Illinois, receiving the degree of Electrical Engineer in 1900. During the years 1901-1906 he taught physics in this institution.

In the fall of 1906 he entered the Graduate Department of the Johns Hopkins University, taking physics as his principal subject and physical chemistry and mathematics as his subordinates. During the years 1906-1908 he attended lectures given by Professors Ames and Wood in physics, by Professor Jones in physical chemistry, and by Dr. Cohen in mathematics.

